WATERTIGHTNESS AND TRANSVERSE STRENGTH OF MASONRY WALLS

SCPI
STRUCTURAL · CLAY · PRODUCTS · INSTITUTE
WASHINGTON D.C.

WATERTIGHTNESS AND TRANSVERSE STRENGTH

of

MASONRY WALLS

by

DOUGLAS E. PARSONS

Chief of Masonry Section
National Bureau of Standards

from

Address Delivered at Annual Meeting
of Structural Clay Products Industry

October 5, 1939

TABLE OF CONTENTS

FOREWORD

During the past five years extensive research has been carried on at the National Bureau of Standards on structural clay products and clay products masonry. The program included investigations of the resistance to weathering of clay products, the fire resistance, compressive and transverse strengths and watertightness of masonry walls, sound absorption and resistance to sound transmission of clay products walls and partitions, and the bond between mortar and various types of clay product units.

Some of this work has been under the direct supervision of Mr. Douglas E. Parsons, Chief of the Masonry Section of the National Bureau of Standards, and in his address before the 1939 Annual Meeting of the Structural Clay Products Institute, he summarized the results of the more recent research and indicated construction practices and simple field tests which should be followed to obtain masonry construction of maximum watertightness and strength.

Mr. Parsons offers no panacea for the elimination of leaky walls. His investigations do indicate, however, that watertight walls can be constructed of materials now readily available in most localities, provided the builder will follow practices which have been found to contribute to watertightness. Satisfactory lateral strength may also be obtained through the observance of a few simple rules.

While most of the research referred to by Mr. Parsons has been reported in the various Bureau publications, obtainable from the Government Printing Office, the Structural Clay Products Institute believes that this summary will materially aid those engaged in the design and construction of clay products masonry in applying the results of research to actual construction, and it takes this opportunity to express its deep appreciation to Mr. Parsons for reducing his address to writing.

HARRY C. PLUMMER,
Director Engineering and Research,
Structural Clay Products Institute.

Prefatory Abstract

The results of research on the factors affecting rain penetration in masonry walls and bond between mortar and structural clay products are discussed. Methods of laying joints in brick masonry which resulted in walls most highly resistant to rain penetration provided either solidly-filled joints or a barrier consisting of a plaster coating of mortar within the interior of a wall. Both the resistance to leakage and the strength of brick-mortar joints were greatest when the bricks were laid as wet as they could be used conveniently and when the mortar had a high water retentivity and was as wet as practicable. When other conditions were alike, the strength of joints increased with an increase in the strength of the mortar, but not in direct proportion.

Watertightness and Transverse Strength of Masonry Walls

DOUGLAS E. PARSONS

I. INTRODUCTION

The results of recent tests identify some of the factors which have major influences on the resistance of masonry walls to rain penetration and the strength and completeness of bond between mortar and brick. They show the conditions favoring the construction of masonry walls which will not leak when exposed to wind-driven rain and which will have a satisfactory resistance to lateral loads. Fortunately, the most important of these conditions may be described in simple terms readily understood by those unfamiliar with the language and methods of testing engineers. This article is limited to a discussion of the portions of the results of research which may be applied without the use of laboratory facilities in the construction of strong and leakproof joints in masonry walls.

II. WATER PERMEABILITY OF MASONRY WALLS

1. Method of Investigation

During the past four years investigations have been conducted at the National Bureau of Standards regarding factors which control the water permeability of masonry walls. The method of investigation was simple and direct. Walls approximately 50 in. high and 40 in. long were constructed by skilled masons. The specimens differed as to kind of brick, mortar and masonry units. Major variables were the method of laying the joints and the completeness of the filling of the joints.

The walls were exposed to conditions simulating the effects of wind-driven rains by subjecting one face to a water spray and air pressure. The apparatus used is illustrated in figures 1, 2 and 3, and consists essentially of an air-tight chamber or box with the wall forming one side. Water is applied at the rate of 13 gal. per lin. ft. of wall per hr. (equivalent to 5.5 in. per hr. over the exposed area of a wall) while a static air pressure of 10 lb. per sq. ft. is maintained on the exposed face. This pressure is approximately equivalent to the maximum of a 50 miles per hour wind. The performances of the specimens are judged by noting the time for dampness and free water to pene-

trate, the rate of leakage, and the proportion of the area of the unexposed face becoming damp in 24 hours.[1]

2. General Observations of Performance

The performances of the walls differed widely. Some of them leaked large quantities of water in less than 3 minutes; others withstood the severe test for more than a week. Both the results of tests of the walls and of the separate materials indicate that the flow of water through solid brick and mortar was exceedingly slow. Moisture penetrated bricks by capillarity from end to end (8 in.) in periods ranging from 1 hour to a day or more. For most bricks, the time exceeded 5 hours.[2] Water penetrated 8 in. of solid mortar by capil-

[1] A detailed description of the methods of testing is given in the paper by Cyrus C. Fishburn, David Watstein, and Douglas E. Parsons, "Water Permeability of Masonry Walls," National Bureau of Standards BMS 7 (1938).

[2] Data on several types of bricks are given by J. W. McBurney, "The Water Absorption and Penetrability of Brick," Proc. Am. Soc. Testing Materials, 29, part II, 711 (1929).

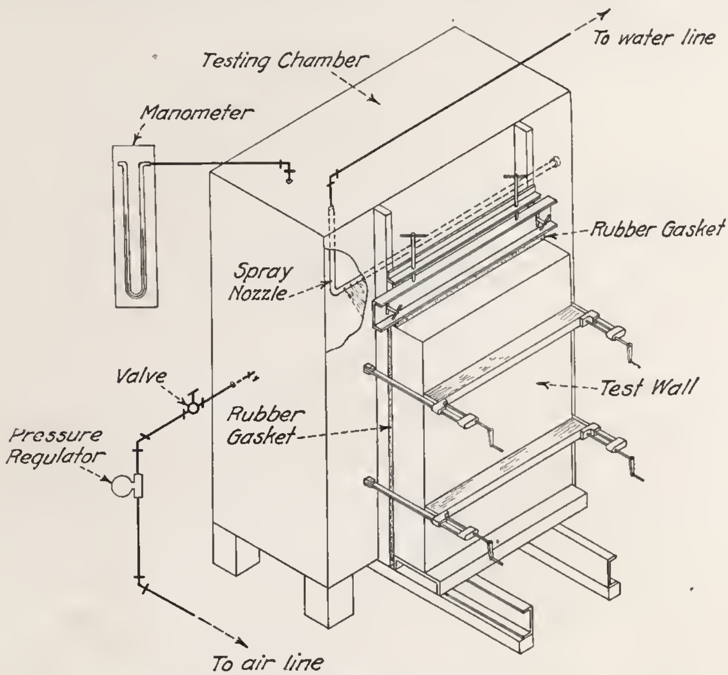

Figure 1

Schematic drawing of Chamber for testing water permeability of walls

Figure 2

Testing chamber with wall removed

larity in periods ranging from a few hours to several days. The rate of penetration decreased when it was necessary for the water to traverse both mortar and brick. A marked delay was observed as the water passed from one material to the other which coincides with the findings of Palmer.[3] The observations show that when walls leaked the water passed through openings or imperfections in the joints rather than through the solid materials.[4]

[3] L. A. Palmer, "Water Penetration Through Brick-Mortar Assemblages," J. Clay Products Inst., 1, 19 (1931).

[4] This was also the experience of other investigators.

F. O. Anderegg, "Construction of Watertight Brick Masonry," J. Am. Ceram. Soc., 13, 351 (1930); and

"Watertight Brick Masonry," Archt. Record, 70, 201 (1931).

J. H. Mallon, "Leaky Brick Walls," Archt. Record, 72, 412 (1932).

L. A. Palmer and D. A. Parsons, "Permeability Tests of 8-in. Brick Wallettes," Proc. Am. Soc. Testing Materials, 34, part II, 419 (1934).

Anon., "Impervious Brick Masonry," Pamphlet, Alton Brick Company, St. Louis, Mo.

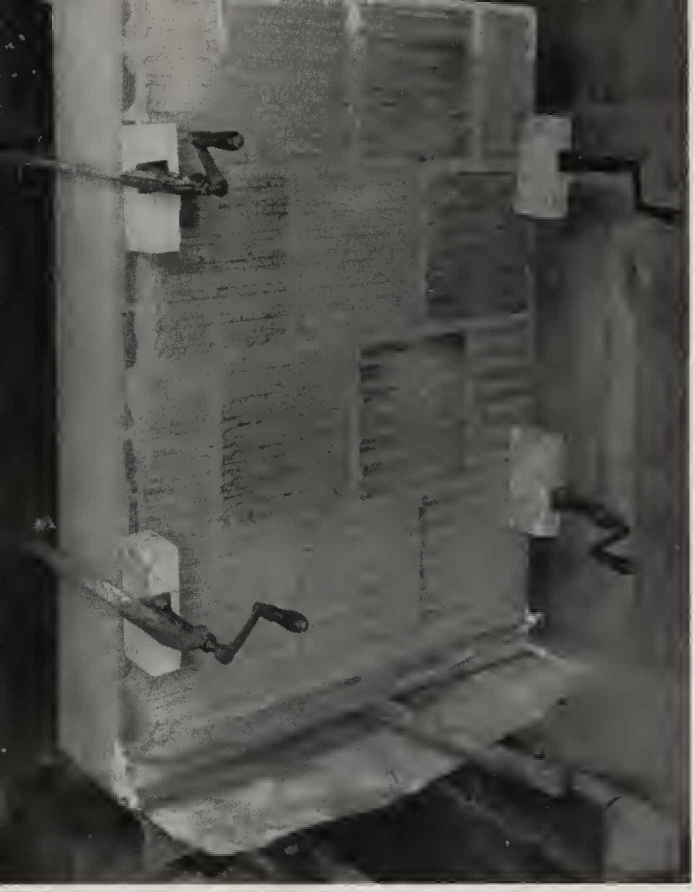

Figure 3

Testing chamber with wall in place

3. Effects of Methods of Laying Brick and Completeness of Filling Joints

Some of the methods of laying the joints in the Bureau's test walls were similar to common practices employed in the construction of walls. Others were experimental and were tried in an attempt to find methods of laying which would be practicable for field operations and would result in masonry having a satisfactory resistance to rain penetration.

The type of joint illustrated in figures 4 and 5 is that commonly observed in structures built primarily for quick sale. Only the minimum amount of mortar required for producing walls of a satisfactory appearance is used. The bed joints are deeply furrowed. The head joints are formed by lightly buttering the face edges of the bricks in place before setting the adjacent ones, using only the mortar scraped from the face joints. The interior vertical joints contain no mortar. All of the walls so constructed leaked; none of them showed sufficient

resistance to indicate the likelihood of satisfactory performance under severe exposures.

A radically different procedure was followed in the construction of specimens illustrated in figures 6 and 7. Mortar for the bed joints was spread to a uniform thickness and the head joints were formed by heavily buttering the ends of stretcher bricks and the edges of header bricks before they were placed. Collar joints, as shown in figure 7, were filled by partially curling the bedding mortar for the backing against the facing, then completing the filling by slushing. Most walls so built were highly resistant to water penetration, but required great care on the part of the mason.

The method of laying joints illustrated in figure 8 was similar to that shown in figures 6 and 7, except that the bed joints were deeply furrowed. This method was found to be much easier for the mason and resulted in walls which usually gave a satisfactory performance.

In the method illustrated in figure 9, resistance against rain penetration was provided by the parging of mortar applied to the back of the facing wythe; otherwise the joints in the masonry contained only the minimum amount of mortar required for a satisfactory appearance. Except for the parging, the joints were similar to those shown in figures 4 and 5. The performances of walls constructed by this method usually were satisfactory; but for walls containing header bricks, leakage sometimes occurred at the level of the header brick where the parging was incomplete, unless the vertical joints in these courses were well filled. Figure 10 illustrates a similar method except that the parging was applied to the face of the backing rather than to the back of the facing. The position of the parging appeared to have no consistent effect upon leakage through the masonry.

When the bricks were laid with the minimum amount of mortar and the open vertical joints were filled course by course by pouring in grout,[5] the walls usually gave a satisfactory performance. The tooling of face joints tended to decrease slightly the leakage through walls but the water permeability was governed largely by the nature of the interior joints.

In general, the methods for laying brick which resulted in walls highly resistant to water leakage were those providing either solidly-filled vertical joints or a barrier consisting of a continuous plaster coating of mortar within the interior of the wall.

[5] Details of the method are described by Chas. H. Fork, "Brick School Built Earthquake-Resistant," Eng. News-Record, 119, 227 (Aug. 5, 1937).

Figure 4

Furrowed bed joints and lightly buttered head joints without mortar in interior vertical joints

4. Effect of Suction Rate of Brick

Early in the investigations it was found that the masons did not build impermeable walls when required to use highly absorptive bricks in a dry condition. In order to investigate more fully the effect of the suction rate [6] (rate of absorption) of brick when laid upon the permeability of walls, specimens were constructed with four different types of bricks, seven methods of laying the joints and two different cement-lime mortars. In addition to these variables, the bricks of moderate and high suction rates were wetted to provide differing rates of absorption at time of laying. Thus there were provided data on the effect of the suction rate of the brick, governed in part by the properties of the dry brick and in part by changing the moisture content prior to use.

All specimens constructed of bricks, having suction rates exceeding 2 oz. per minute, showed ratings of Fair to Very Poor in the permeability test. When the suction rate ranged between 0.7 and 2 oz. per minute, the ratings were either Good or Fair. When it was not more than 0.5, most specimens rated Excellent, and the rest Good. Thus, irrespective of the kind of brick, mortar or workmanship (provided the joints were reasonably well filled), the resistance of the walls to moisture penetration increased with a decrease in the suction rate of the brick at time of laying. Satisfactory walls were built with each kind of brick if the more absorptive ones were wetted before laying.

[6] The suction rate of a brick is the amount of water absorbed by the brick when immersed flatwise to a depth of ⅛ in. for 1 minute. It may be made as small as desired hy wetting the brick before use.

However, it was necessary to wet highly absorptive bricks before laying in order to obtain walls having a satisfactory resistance to moisture penetration.

5. Effect of Kind of Mortar

The essential quality of mortar was found to be workability and water retentivity.[7] Workable mortars which stiffened slowly when in contact with absorptive units were desired by the masons, and more satisfactory walls were obtained with them than with mortars which stiffened rapidly. No consistent relation was found between the chemical composition of mortar and the performance of the walls in the permeability test. The workability of the cement-lime mortars depended more upon the workability of the lime than upon the ratio of cement to lime in the mortar. Although it was possible to construct walls having a high resistance to water penetration with any of the mortars used, provided absorptive bricks were wetted before laying, it was much easier for the masons to construct such walls with mortars of good workability. The mortars having poor working qualities not only stiffened rapidly when in contact with absorptive units, but also tended to segregate and to "bleed" or "weep" when used with bricks of extremely low suction rates.

---

[7] Although a generally accepted method for measuring the workability of mortars has not been devised, it is closely related to water retentivity. Usually, the higher the water retentivity of a mortar, the greater its workability. Water retentivity is now commonly measured by the flow after suction test described in the Federal Specification SS-C-181b for Masonry Cement. This specification contains the requirement that "Standard mortar after suction for 60 seconds shall have a flow greater than 65 percent of that immediately after mixing."

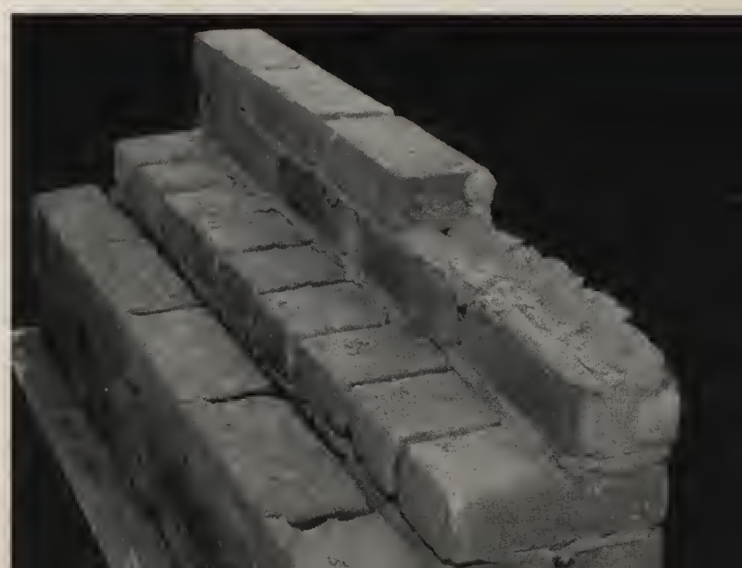

Figure 5

Furrowed bed joints and lightly buttered head joints without mortar in interior vertical joints

6. Effect of Design of Walls

Reducing the number of header bricks in walls of common American bond, by using half bricks for two-thirds of the bricks in each header course, did not have a significant effect on permeability. However, walls containing no header units and having either a continuous parging within the wall or the space between wythes filled with grout usually showed a high resistance to leakage. Walls with a facing of low absorptive brick and a backing of highly absorptive brick gave a better performance than similar walls constructed entirely of either type of brick. The resistance of walls with brick facings and hollow unit backings depended chiefly upon the permeability of the facing and parging.

7. Treatments for Stopping Leaks

None of the several types of coatings of clear liquid waterproofings was effective in preventing leakage through walls unless accompanied by other treatments to seal the openings in the joints. Some benefit was derived from their use on brick masonry composed of highly absorptive bricks, provided the joints were well filled with mortar or were sealed by another treatment. Openings in joints were effectively sealed by repointing or by brushing the surfaces of the joints with a 1:1 mixture of portland cement and fine sand.

8. Effects of Exposures

After being tested for permeability, a few of the walls were exposed to several cycles of wetting and drying and a few to 30 cycles of heating and cooling over a range from 20 to 125° F., and then retested. The rest were exposed outdoors and retested after exposure to natural weathering for one year. The permeabilities of the walls of brick masonry were not affected significantly, irrespective of the kind of brick or mortar used. The permeabilities of those having brick facings and hollow unit back-up increased slightly as did those with stucco facings. These results indicate that differential movements between mortar and brick were not a *major* cause of leakage through the brick walls, as there was not a significant difference in the performances of walls composed of mortars and bricks of widely different rates of expansion under changes of temperature and moisture content. Obviously, the differential movements between differant portions of large walls, which sometimes cause long structural cracks in masonry, were of very limited extent in the walls only 50 in. high and 40 in. long.

III. TRANSVERSE STRENGTH OF MASONRY WALLS

1. Methods of Investigation

As a part of the research program of the National Bureau of Standards on building materials and structures, the transverse strengths of masonry wall constructions have been investigated. Reports of the tests on nine types of wall constructions are included in "Building Materials and Structures," Reports BMS 5, BMS 23, and BMS 24.[8] Wall specimens, approximately 8 ft. high by 4 ft. wide, were supported against horizontal movement by steel rollers placed 7 ft. 6 in. apart while two equal loads were applied on the opposite side of the specimen, one at each quarter length of the span, as illustrated in figure 11. The total load at failure, reduced to an equivalent uniformly distributed load, is reported as the maximum load supported on a 7 ft. 6 in. span.

Factors affecting the bond between mortar and brick have also been studied. These investigations included the fabrication and testing of specimens consisting of either two or three bricks bonded together flatwise by means of mortar joints. After aging, the specimens were tested to determine the strengths of the brick-mortar joints either in shear or in tension.

2. General Observations

Each of the non-reinforced wall specimens which was subjected to the transverse test failed by rupture of either the mortar or the bond between the masonry units and the mortar at a bed joint. The average equivalent maximum uniform loads for the non-reinforced walls ranged from 125 lb./ft.^{2} for 8-in. solid walls having joints completely filled with a strong mortar to 21.5 lb./ft.^{2} for a brick-tile cavity wall built with a mortar of lower strength. The average transverse strength of the 8-in. reinforced and grouted brick walls was 203 lb./ft.^{2} For the non-reinforced brick walls the transverse strength was affected by the strength of the joints and by the design of the wall. Solid masonry

[8] BMS 5, "Structural Properties of Six Masonry Wall Constructions," by Herbert L. Whittemore, Ambrose H. Stang, and Douglas E. Parsons;

BMS 23, "Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc.," Herbert L. Whittemore, Ambrose H. Stang, and Douglas E. Parsons:

BMS 24, "Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute," Herbert L. Whittemore, Ambrose H. Stang and Cyrus C. Fishburn.

BMS 5 also contains a list of references to publications giving the results of strength tests of various types of masonry walls.

Copies of these reports may be obtained from the Superintendent of Documents, Washington, D. C., for 10 cents each.

Figure 6

Solidly-filled joints and smooth spread bedding

walls were stronger than hollow walls or walls constructed of hollow units.

In the strength tests of the small brick-mortar specimens the failures of joints occurred by rupture of the bond, the brick or the mortar. With mortars of extremely low tensile strength, the failures usually were within the mortar. Failures in the brick took place only with highly laminated bricks or those of uncommonly weak structure when used with mortars of high strength. An examination of the surfaces of the bricks and mortar after failure showed that frequently only portions of the surfaces had been in intimate contact. The most intimate and complete contact seemed to be obtained with bricks of low suction rates at time of laying. Further, the bond usually tended to be more complete with mortars of good working properties.[9] The strength of the joints made with workable mortars and bricks of low or moderate suction rates increased with an increase in the strength of the mortar, but not in direct proportion.

3. Effect of Method of Laying Brick

In the transverse tests of wall specimens, walls constructed with mortar joints similar to those illustrated in figures 6 and 7 were approximately 70 percent stronger than those constructed with the type of joints illustrated in figures 4 and 5. An inspection of the reinforced grouted

[9] L. A. Palmer and D. A. Parsons, "A Study of the Properties of Mortars and Bricks and Their Relation to Bond," J. Res. NBS, 12, 609 (1934) RP 683.

M. O. Withey, "Recent Experiments on Masonry Building Materials Made in the Materials Testing Laboratory at the University of Wisconsin," Bul. Assoc. State Eng. Soc., July 1935.

Figure 7

Solidly-filled joints and smooth spread bedding

wall after test indicated that the grouting method of filling joints contributed to the high strength of this wall, as well as the steel reinforcement. The strengths of the mortar bond specimens were affected by the completeness with which the mortar was spread and compacted and by the pressure used in forming the joints.

4. Effect of Suction Rate of Brick

As previously indicated the completeness of the contact of mortar to brick was markedly affected by the suction rate of the brick at time of laying. With bricks of high suction rates, the mortar seemed to have made complete contact with only a relatively small proportion of the surfaces of the bricks. Moreover, there was a tendency for the strength of the joints to increase rapidly as the suction rates of highly absorptive bricks were decreased below 2 oz. per minute. The maximum strengths with mortars having the consistency desired by masons usually were obtained when the suction rate was between 0.2 and 0.8 oz. per minute.

5. Effect of Consistency of Mortar

Data obtained by Professor M. O. Withey [10] show that the tensile strength of brick-mortar joints tends to increase with the flow (wetness) of the mortar at time of use, except possibly for bricks having suction rates less than 0.2 oz. per minute. These results indicate that the most complete contact of mortar with brick and joints of highest

[10] "Recent Experiments on Masonry Building Materials Made in the Materials Testing Laboratory at the University of Wisconsin," Bul. of the Assoc. State Eng., July 1935.

tensile strength are likely to be obtained if the mortar is as wet as may be used conveniently. Also that the retempering of mortar which has not begun to harden should be encouraged.

6. Effect of Water Retentivity of Mortar

The strength of brick-mortar joints tended to increase with an increase in the water retentivity of the mortar. This tendency was greatest with bricks of high suction rates.

7. General

The results of both the permeability and the bond tests indicate that the difficulty of obtaining a satisfactory initial union of mortar with brick is mechanical and not chemical in nature. Incomplete bond and leakage may result from the use of an insufficient amount of mortar, leaving unfilled spaces in the joints. Also, there may be poor contact

Figure 8

Furrowed bed joints and filled vertical joints

of mortar with brick, in spite of efforts of the mason, if the mortar is too dry and stiff at the time contact is made. With bricks having too high a rate of absorption, there is a tendency for the mortar to lose water rapidly and to become too stiff to form a complete bond with the brick. Although the rate of stiffening of mortar when in contact with absorptive units is minimized by the use of mortars of easy working

properties and high water-retaining capacity, strong and watertight joints were not obtained with mortars which were best in these respects unless bricks having high rates of absorption were wetted before laying.

IV. APPLICATION OF RESULTS

1. Method of Constructing Watertight and Strong Joints

A desirable method for laying joints in masonry is one which provides a barrier against the entrance of water and a complete bonding of the mortar with the masonry units at a minimum cost. The moisture barrier may be provided by means of solidly filled joints throughout the wall, but especially in the facing, or it may consist of a plaster coating of mortar applied to the face of the backing or to the back of the facing. Although there appears to be no simple alternative, a choice of methods for obtaining well-filled joints is possible. Mortar may be applied to

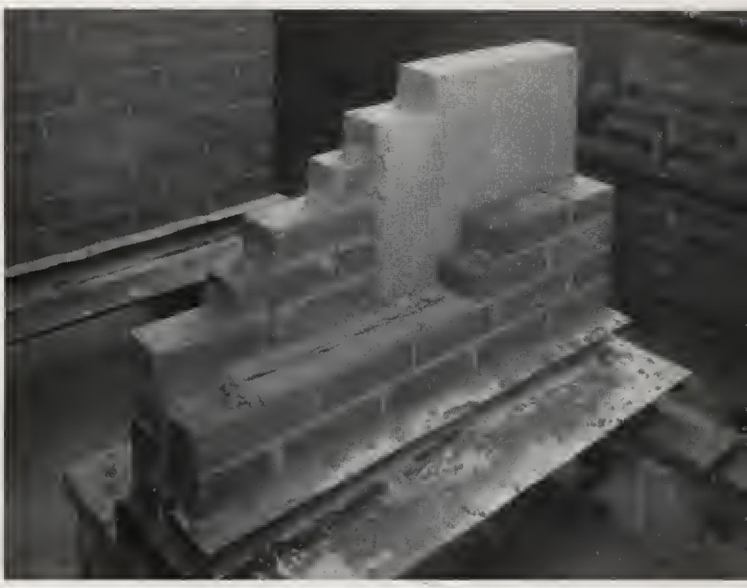

Figure 9

Wall with 3/8-in. parging of mortar on back of facing

the ends of stretcher bricks and the sides of header bricks before they are laid, thus filling vertical joints at the time these bricks are placed. Filling may be accomplished by the pick and dip method, in which mortar is thrown on the bed joint immediately prior to the laying of each brick. The brick is then shoved into position which tends to fill both the horizontal and the vertical joints. Or the vertical joints may

be filled by slushing or by grouting after the bricks have been placed. The last methods may not be as effective as the others unless the suction rate of the brick and the workability of the mortar or consistency of the grout are within the optimum ranges. Although the leakage resistances of walls with furrowed bed joints were not appreciably inferior to those with solidly filled bed joints (however obtained), the transverse strengths were less.

2. Controlling Suction Rate of Brick

The most desirable suction rates for bricks were from 0.2 to 0.7 avoirdupois ounces per minute, both for walls of high resistances to rain penetration and to transverse loads and also for complete and strong bonding of the mortar to the units. Walls which did not leak were constructed of brick having suction rates less than 0.2 oz. However, there was a tendency for these bricks to "float" and for the walls to become distorted by the bricks moving out of position, thus delaying construction. Usually floating was not troublesome when there was no surface water on the brick. An exact control of the suction rate was not necessary. The masons easily judged when the bricks were too wet. Perhaps the most satisfactory method for wetting highly absorptive brick is to spray them in a pile until water flows from all portions, several hours prior to their use. As the more absorptive units tend to absorb water more rapidly than those of lower absorption, the spraying may tend to produce uniformity in the suction rate.

3. Controlling Mortar Properties

The results of investigations indicate that it is possible to construct walls having a high resistance to rain penetration with mortars of poor working qualities. However, it is much easier when the workability of the mortar is such that a minimum effort is demanded from the mason. Although masons have their own technique in judging the working qualities of mortars, others may gain a rough estimate by observing their performance in two respects: first, a mortar of poor workability stiffens rapidly when on an absorptive unit, and secondly, it tends to "bleed," that is, to segregate with a separation of the water when standing on an impervious base. Good workability and high strength are not incompatible, and, by an appropriate choice of materials, it is not difficult to prepare mortars of excellent working properties which will develop high strengths.[11] General requirements for and proper-

[11] M. O. Withey and K. F. Wendt, "Tests of Mortars for Reinforced Brick Masonry," Proc. Am. Soc. for Testing Materials, 35, part II, 426 (1935).

Figure 10

Wall with 3/8-in. parging of mortar on face of backing

ties of mortars and mortar materials are discussed in detail in Brick Engineering.[12]

V. CONCLUSION

The protection against rain and lateral forces afforded by the walls of a building may depend more upon the design of the structure and its details than upon the inherent resistance of the walls. For example, suitable flashings over openings, which are always desirable, are necessary for assurance against leakage with walls having water

[12] Published by the Structural Clay Products Institute, Washington, D. C.

Figure 11

Method of making transverse tests of walls

permeable facings. Resistance of walls to horizontal forces depends largely upon the strength and spacing of the lateral supports. For a particular design, however, the watertightness and transverse strength of masonry walls are governed largely by qualities of the joints.

The conditions favoring the construction of strong and leakproof joints in masonry may be stated more completely and precisely in values measurable by means of laboratory instruments and methods than in general terms. However, their statement in general terms may be helpful in directing attention to the important factors and in providing a rough guide to builders.

The resistance of masonry walls to rain penetration was governed more by the method of laying the joints than by any other factor. Most walls with solidly-filled vertical joints (however obtained) or with a continuous parging of mortar in the interior were highly resistant. The likelihood of obtaining a complete and strong bond of mortar to brick and tight joints was greatest when the bricks were as wet as they could be without excessive floating and the joints were completely filled with a water retentive mortar containing the maximum amount of water compatible with satisfaction of the mason.